Implications of Uncertainty and Spillovers for Access and Benefit Sharing Arrangements

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Abstract

One of the objectives of the 1992 Convention on Biological Diversity is to create access to genetic resources and benefit-sharing (ABS) systems that incorporate the environmental, social, and economic aspects of sustainable development. Under the Convention, governments have sovereignty over their genetic resources but also the responsibility of using them sustainably. This provision is particularly relevant for biologically-abundant developing countries as it offers a direct means of reducing the financial pressures against conservation of ecosystems and natural habitats, particularly in light of recent. This paper examines the impacts of a benefit-sharing system involving royalties and governmental ownership of genetic resources in a two-firm research and development (R&D) market with uncertainty and information spillovers. Royalties are shown to reduce the research output of the taxed firm, which results in much lower expected government revenues when the research output of a competing firm is a strategic subsitute relative to when it is a strategic complement. Further, taxation alone is generally inferior to a combination of taxation/subsidization of successful products and research costs. The paper shows that subsidization rather than taxation of successful products may even be optimal under particular types of uncertainty.

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1 Introduction

Biodiversity preservation, or the protection of variety among species, is of significant concern to many governments, but is particularly relevant to the developing world. While individuals may derive benefits from species and their diversity, the public good aspect of these resources makes it difficult to finance the costs of conservation. In order to mitigate the adverse effects of the free good (or public good) nature of biological resources on their conservation and sustainable use, initiatives have been undertaken since the early 1990s, including the Convention on Biological Diversity (with 188 States and the European Community since it opened for signature at the Earth Summit in Rio de Janiero, Brazil, in 1992), to create access to genetic resources and benefit-sharing (ABS) systems that would incorporate the environmental, social, and economic aspects of sustainable development. One of the aims of these initiatives, and particularly of the Convention, is the use of the economic incentives created by the potential commercial value of genetic resources towards the conservation of these same resources. More specifically, in acknowledging the principle of ownership according to which genetic resources are recognized to be the property of those nations in whose sovereign territories they are located, the Convention provides that, when a biological resource is used for a commercial application, the country of origin of such a resource has the right to benefit.[1]

Under the Convention, governments are responsible for developing national biodiversity strategies and action plans integrating the objectives of consersation and sustainable use of biodiversity. In order to achieve these goals, governments would need to consider the goods and services provided by biodiversity and promote activities that ensure an equitable sharing of the benefits from such goods and services. These benefits could include monetary payments, samples of what is collected, transfer of biotechnology equipment and know-how, and shares of any profits from the use of the resource. Sharing in the profits is of particular relevance as it provides a direct means for supporting conservation. Extracting rents from biodiversity prospecting, or investigating natural sources for commercially valuable pharmaceutical products or biotechnology, is indeed a method for financing the conservation of biological resources that has been gaining in popularity of use. The provision

[1] The objectives of the Convention as set out in article 1 are "the conservation of biological diversity, the sustainable use of its components, and the fair and equitable sharing of the benefits arising out of the utilization of genetic resources, including by appropriate access to generic resources and by appropriate transfer of relevant technologies, taking into account all rights over those resources and to technologies, and by appropriate funding" (http://www.cbd.int/convention/convention.shtml).

that nations have sovereignty over their genetic resources but also the responsibility for conserving their biological resources and for using them in a sustainable manner is especially important for developing countries. "In situ" conservation of ecosystems and natural habitats is quite expensive in terms of both preservation costs and the lost alternative use of land; if biodiversity prospecting were a substantial and continual revenue generator for governments, the pressures against conservation in developing countries, where biological resources are in abundance but economic growth and biodiversity preservation are perceived as being much more incompatible objectives than in developed countries,[2] could be lessened through compensation for lost opportunity costs. A number of pharmaceutical companies (including some of the world's largest) and agencies have explored or are currently examining species for potential new products, as seed firms in agriculture have been doing for many years. In 1993, most of the top 150 prescription drugs used in the U.S. (79 percent) were nature-inspired compounds, semisynthetics and their analogs, and natural products or chemicals found in nature (Fanning, 1995). Correspondingly, a number of governments, particularly in developing countries, have offered private firms the opportunity to sample species from within their borders in return for a share of the revenues (royalty) from any products resulting from the research.

South Africa, for example, which is one of the most biologically diverse countries in the world, has been attempting to implement some of the Convention's principles through its 2003 *National Environmental Management: Biodiversity Bill*.[3] Chapter 6 of this Bill is of particular interest for the purpose of this paper as it is intended to regulate bioprospecting of genetic resources through a permit system and ensure that the benefits arising from the commercialization through bioprospecting of traditional uses or knowledge of indigenous biological resources are equitably shared with persons or communities practising these traditional uses or knowledge. In 1995, the Philippines adopted a Presidential Executive Order (EO 247) to regulate bioprospecting which has laid down three essential conditions for those interested in prospecting for biological resources in the Philippines, namely, (1) a research agreement with the government, (2) prior informed consent, and (3) sharing of benefits with local communities and indigenous peoples.[4] In 1996, the Andean

[2] For example, 70 percent of the 3,000 species known to have anti-cancer properties are found in tropical forests (Sedjo, 1992).

[3] See http://www.info.gov.za/gazette/bills/2003/b30d-03.pdf.

[4] The minimum terms of a research agreement include: (1) a limit on the samples to be collected and exported; (2) a complete set of all speciments; (3) access to collected specimens and relevant data deposited abroad; (4)

Community, consisting of Bolivia, Colombia, Ecuador, Peru, and Venezuela, adopted Decision 391 establishing a legal framework for bioprospecting which tries to ensure the sharing of the benefits derived from ABS-related activities with the countries where genetic resources and biologically derived materials are collected.[5] In 1998, Costa Rica, the country with the most documented experience implementing bioprospecting projects,[6] enacted the Law of Biodiversity No. 7788 which, unlike other ABS laws and policies, requires bioprospectors to invest a percentage of their research budget (up to 10%) and royalties (up to 50%) directly in the areas where genetic resources are collected.[7] In Mexico, Articles 87 and Article 87 BIS of the 1988 Ecological Equilibrium and Environmental Protection General Act (EEEPGA), which were introduced in the 1996 reform of the act, regulate ABS issues; specifically, these articles incorporate the three main principles stated in the Convention on Biological Diversity, namely, prior informed consent, mutually agreed terms, and benefit sharing, but do not provide guidelines as to how these principles can be implemented.[8]

Several studies have previously suggested that biodiversity prospecting can be used as a potential tool for conservation, such as Farnsworth and Soejarto (1985), Principe (1989), Wilson (1992), Reid et al. (1993), and Rubin and Fish (1994). Another subsequent branch of the literature has questioned the effectiveness of such a tool, citing either low private values of the "marginal" species (Simpson et al., 1996) or low royalty revenues to source governments (Barbier and Aylward, 1996).[9] Using the same numerical examples employed by Simpson et al. (1996) but amending the analysis to account for the importance of information rents for promising leads, Rausser and Small (2000) have however suggested much greater economic benefits from bioprospecting than previously derived ($9,200 per hectare of western Ecuador or roughly 450 times greater than the value calculated by Simpson et al.). Furthermore, with the development of better ways of examining

information about any commercial product derived from the activities; (5) provision for payments in terms of royalties and other compensation in cases of commerical use; (6) trasfer of equipment; (7) prospecting fee; (8) trasfer of technology for commercial use in cases of endemic species (http://www.chanrobles.com/eo247.htm or http://biodiv.org/doc/measures/abs/msr-abs-ph1-en.pdf).

[5]See http://www.comunidadandina.org/INGLES/normativa/D391e.htm.

[6]The initial agreement that triggered subsequent ones was actuallly signed in 1991 between the Instituto Nacional de Biodiversidad in Costa Rica (INBio) and a major pharmaceutical company (Merck & Co.). This agreement remains one of the most successful

[7]See http://www.grain.org/brl_files/costarica-biodiversitylaw-1998-en.pdf.

[8]The 1999 Wildlife General Act and the 2003 Sustainable Forestry Development General Act include ABS provisions that apply specifically to wildlife and forest resources, respectively.

[9]Private values typically ignore non-use values or non-excludable use values. Contingent valuation and travel cost studies of estimating existence and option values for different environmental amenities, such as Pearce (1990), Barbier et al. (1994) or Brown and Henry (1993), suggest that social values not included in private decisions may be significant.

and using genetic resources in the agriculture, pharmaceutical, and biotechnology industries (e.g., high-throughput analysis, combinatorial chemistry, bioinformatics, and genomics), the economic value of the information contained in their genes and biochemical compounds has been increasing (Carrizosa et al., 2004). New methods of bioprospecting which rely upon combining databases of natural history with ecological and evolutionary theory have recently been applied to many industries outside pharmaceuticals, including biological control, bioremediation, construction engineering, shipping, environmental monitoring, mining, industrial materials, manufacturing, and environmental restoration.[10] Although an assessment of their impacts is premature, these new developments are expected to increase the economic benefits of bioprospecting in the future as more species are identified as useful, thus potentially increasing the frequency of lead discovery.

In light of the above, the implications of uncertainty and spillovers for a benefit-sharing system involving royalties and governmental ownership of genetic resources are examined in the context of a two-firm, two-country model of research and development. As below shown, the effectiveness of taxes/royalties depends on the nature of the uncertainty in the research and development process, which manifests itself through the strategic complementarity or substitutability of the firms' research expenditures. The relationship between royalties and other surplus extraction methods is examined in a model where two prospecting firms compete through R&D for the same product (prize). One firm uses samples from a country with the government planning the surplus extraction, while the other is not subject to any intervention. The R&D output of both firms is subject to outcome uncertainty and information spillovers.

2 The Model

Biodiversity prospecting is an example of R&D and is thus subject to competition among firms; accordingly, the model presented here is related to the literature on strategic R&D and trade theory.[11] More specific to this paper, Brander and Spencer (1983), Dixit (1984), Spencer and Brander (1994), and Eaton and Grossman (1986) consider international R&D competition under certainty, examining price and quantity competition by two or more firms. Bagwell and Staiger

[10]Such sampling of ecosystems for potential drugs, which represents a major advance on the traditional pharmaceutical protocols, has been referred to as ecologically driven drug discovery, biorational approach, or hypothesis-driven drug discovery (Beattie and Ehrlich, 2004; Coley et al., 2003).

[11]Brander (1995) provides a survey of this literature.

(1992, 1994) add uncertainty in production costs while Muniagurria and Singh (1997) and Leahy and Neary (1999) introduce spillovers.[12] In a framework most closely related to the one adopted in this paper, Zhou (2002) combines both uncertainty and spillovers in R&D. In the context of a two-firm R&D model with uncertainty and information spillovers, the present study considers the design of an access and benefit sharing arrangement, with emphasis on the benefit sharing instruments or regulations, in a country that has control over its genetic resources and wishes to stimulate bioprospecting by a private firm in order to support the effective management and conservation of its biodiversity. Aside from the application, the present analysis differs from previous work in the nature of the government objective function. Each of the studies above is in fact concerned with the welfare of the firm (industrial policy) as opposed to rent extraction; governments in the noted literature could run deficits in order to encourage R&D spending to improve welfare, which a government interested in raising funds for biodiversity protection would clearly not do.

Two risk-neutral firms are assumed to be selecting their respective levels of R&D input in the hope of creating a new pharmaceutical or biotechnology product. One firm purchases its R&D input (also referred to as sampling intensity) from outside the country in question and is not subject to any rent extraction policy. The other firm purchases its input from the country concerned with profiting from its biodiversity and applying such profits to conservation. The value (net of production costs) of a successful product is constant at $\bar{v}$, but the outcome depends on the rank order and not on the absolute difference between expenditures. In this way, only the firm with the higher R&D level receives this amount, while the losing firm receives no return (this value arises from the exclusive monopoly profits gained from perfect patent protection on the product for a finite period). Sampling and testing for viable products has a cost to the firms which depends on the number of species sampled, $c(s)$, with $c' > 0$ and $c'' > 0$. For simplicity, the probability of finding multiple successful products is assumed to be zero.

Although the foreign firm is not subject to government intervention, we consider two different ways the domestic firm can be taxed. The first is to place a royalty on the value of a successful product, if found, which has been the common method used in recent biodiversity prospecting contracts (e.g., the INBio-Merck agreement in Costa Rica and the Astra Zeneca agreement in Queensland, Australia). When this is the only instrument employed, the royalty (t) is shown to

[12] Coe and Helpman (1995) show that international R&D spillovers are quite significant.

always be positive (tax) and never negative (subsidy), as the tax serves to reduce the reward earned from R&D. A second instrument considered here is a tax or subsidy on each unit of the input (p). Again, if this is the only method, this per unit charge is always positive, thus a tax. However, when both instruments are employed, it is shown that the government may employ a tax on a successful product and a subsidy on sampling, a subsidy on successful products and a tax on sampling, or a tax on both. Factors determining which combination is selected include the nature of the uncertainty (which has implications for strategic competition), the extent of information spillovers between the two firms, the value of the final product, and costs to both the firm (for sampling) or the government (for conservation).

The equilibrium examined here is subgame perfect. Section 3 describes the (simultaneous) competition between the two firms in the second stage of the game, given the government tax/subsidy instruments. Section 4 considers the selection of the instruments to maximize rent extraction by the government. Finally, section 5 provides concluding remarks.

3 Uncertainty, spillovers, and the sampling intensity of the two firms

Each firm selects its desired sampling intensity s, but its overall R&D level depends on the degree of spillovers from the foreign firm as well as on a random variable. With the exogenous percentage of information lost to the other firm and gained from the other firm denoted by γ $(0 \leq \gamma \leq 1)$ and the random variable denoted by ε, the realized sampling intensity of firm i is given by

$$S_i = s_i + \gamma s_j + \varepsilon_i \tag{1}$$

and the realized sampling intensity of the foreign firm j is given by

$$S_j = s_j + \gamma s_i + \varepsilon_j, \tag{2}$$

where ε_i and ε_j are identically and independently distributed. The distribution function of ε, which is twice differentiable, is given by $F(\varepsilon)$, with the first derivative, denoted by $f(\varepsilon)$, representing the density function. As in Zhou, the R&D choice shifts the density function without changing its other properties.[13] The winner of the R&D competition is the firm with the higher realized sampling

[13]The uncertainty in Bagwell and Staiger alters the density function of production costs. For more detail on the specification chosen here, see Zhou.

intensity, in the same manner as in a labor tournament analysis of the type in Lazear and Rosen (1981).

For firm i to win, its realized sampling intensity S_i must be larger than that of the competing firm S_j, or equivalently

$$(1-\gamma)(s_i - s_j) + \varepsilon_i > \varepsilon_j, \tag{3}$$

so that the probability of developing the successful product is $F((1-\gamma)(s_i - s_j) + \varepsilon_i)$ for a given ε_i. Over all possible values of ε_i, the expected probability of developing the successful product is $\int_{\underline{\varepsilon}}^{\bar{\varepsilon}} F((1-\gamma)(s_i - s_j) + \varepsilon_i) f(\varepsilon) d\varepsilon$, where $\underline{\varepsilon}$ and $\bar{\varepsilon}$ are the lower and upper bounds of the distribution function. Given the government's instruments t and p, firm i's expected profits are

$$\pi_i = (1-t)\bar{v} \int_{\underline{\varepsilon}}^{\bar{\varepsilon}} F((1-\gamma)(s_i - s_j) + \varepsilon_i) f(\varepsilon) d\varepsilon - c(s_i) - ps_i, \tag{4}$$

that is, the expected value of the successful product (net of any royalty) less sampling costs and per unit charges. Maximizing this expected profit yields the first-order condition for firm i

$$(1-t)(1-\gamma)\bar{v} \int_{\underline{\varepsilon}}^{\bar{\varepsilon}} f((1-\gamma)(s_i - s_j) + \varepsilon_i) f(\varepsilon) d\varepsilon - c'(s_i) - p = 0, \tag{5}$$

whereby the firm samples up to the point where the additional expected value of the successful product, net of taxes (or subsidies) and spillovers, from the greater likelihood of winning the competition, equals the sum of the marginal sampling cost and per unit charge.[14] The reaction function for firm i is then

$$\frac{\partial s_i}{\partial s_j} = -\frac{\frac{\partial^2 \pi_i}{\partial s_i s_j}}{\frac{\partial^2 \pi_i}{\partial s_i^2}} = -\frac{-(1-t)(1-\gamma)^2 \bar{v} \int_{\underline{\varepsilon}}^{\bar{\varepsilon}} f'((1-\gamma)(s_i - s_j) + \varepsilon_i) f(\varepsilon) d\varepsilon}{(1-t)(1-\gamma)^2 \bar{v} \int_{\underline{\varepsilon}}^{\bar{\varepsilon}} f'((1-\gamma)(s_i - s_j) + \varepsilon_i) f(\varepsilon) d\varepsilon - c''(s_i)}. \tag{6}$$

By virtue of the second-order condition for a maximum, the denominator of (6) is negative. Firm i's reaction function is therefore negatively sloped when $f' > 0$, is perfectly horizontal (and thus independent of s_j) when $f' = 0$, and is positively sloped when $f' < 0$. When the two firms' sampling intensities move in the same direction ($f' < 0$), the two inputs are strategic complements; when the sampling intensities move in opposite directions ($f' > 0$), the inputs are strategic substitutes.[15]

[14] The second-order condition depends on the sign of f' and is therefore not automatically satisfied. The assumption made here is that marginal costs are increasing at a sufficient rate and/or γ is sufficiently large to satisfy the second-order condition for a maximum.

[15] Bulow et al. (1985) describe in detail strategic complementarity and substitutability in R&D competition. In summary, strategic substitutability in R&D refers to a situation where a firm increases its profits by reducing R&D spending in response to an increase in its competitor's spending on R&D; equivalently, strategic complementarity occurs when a firm's profits increase when the firm spends more on R&D in response to an increase in spending on R&D by its competitor.

Globally monotonic density functions include the exponential ($f' < 0$), the uniform ($f' = 0$), and the power ($f' > 0$) distributions. As in Zhou, the sign of f' can be interpreted as an indication of the prevalence of opportunities available in the market, with higher values suggesting greater opportunities.

The foreign firm has the same cost function but is assumed to face no taxes or per-unit charges, so that its expected profits are

$$\pi_i = \bar{v} \int_{\underline{\varepsilon}}^{\bar{\varepsilon}} F((1-\gamma)(s_j - s_i) + \varepsilon_j) f(\varepsilon) d\varepsilon - c(s_j) \tag{7}$$

and s_j is chosen according to

$$(1-\gamma)\bar{v} \int_{\underline{\varepsilon}}^{\bar{\varepsilon}} f((1-\gamma)(s_j - s_i) + \varepsilon_j) f(\varepsilon) d\varepsilon - c'(s_j) = 0, \tag{8}$$

which is equivalent to (5) without taxes or per unit charges.

Conditions (5) and (8) describe the outcome of the second stage of the game, given the government's taxes set in the first stage (examined below). The sensitivity of the second stage equilibrium can be found from the total derivatives of these conditions, which can be written as follows

$$\begin{bmatrix} \delta_{11} & \delta_{12} \\ \delta_{21} & \delta_{22} \end{bmatrix} \begin{bmatrix} ds_i \\ ds_j \end{bmatrix} = \begin{bmatrix} (1-\gamma)\bar{v} \int_{\underline{\varepsilon}}^{\bar{\varepsilon}} f((1-\gamma)(s_i - s_j) + \varepsilon_i) f(\varepsilon) d\varepsilon & 1 \\ 0 & 0 \end{bmatrix} \begin{bmatrix} dt \\ dp \end{bmatrix}, \tag{9}$$

where

$$\delta_{11} = (1-t)(1-\gamma)^2 \bar{v} \int_{\underline{\varepsilon}}^{\bar{\varepsilon}} f'((1-\gamma)(s_i - s_j) + \varepsilon_i) f(\varepsilon) d\varepsilon - c''(s_i), \tag{10}$$

which is negative by the second-order condition of firm i's profit maximization,

$$\delta_{12} = -(1-t)(1-\gamma)^2 \bar{v} \int_{\underline{\varepsilon}}^{\bar{\varepsilon}} f'((1-\gamma)(s_i - s_j) + \varepsilon_i) f(\varepsilon) d\varepsilon, \tag{11}$$

$$\delta_{21} = -(1-\gamma)^2 \bar{v} \int_{\underline{\varepsilon}}^{\bar{\varepsilon}} f'((1-\gamma)(s_j - s_i) + \varepsilon_j) f(\varepsilon) d\varepsilon, \tag{12}$$

and

$$\delta_{22} = (1-\gamma)^2 \bar{v} \int_{\underline{\varepsilon}}^{\bar{\varepsilon}} f'((1-\gamma)(s_j - s_i) + \varepsilon_j) f(\varepsilon) d\varepsilon - c''(s_j), \tag{13}$$

which is negative by the second-order condition of firm j's profit maximization. The signs of the off-diagonal elements of the Jacobian depend on whether the two inputs are strategic substitutes or strategic complements. When the sampling intensities of the two firms are substitutes, the off-diagonals are both negative; when the sampling intensities of the two firms are complements, the off-diagonals are both positive. For stability, the determinant of the Jacobian (denote by $|\Delta|$) is assumed to be strictly positive as in Bagwell and Staiger.

Hence, firm i performs less sampling when the royalty on the successful product increases as implied by

$$\frac{\partial s_i}{\partial t} = \frac{(1-\gamma)^3 \bar{v}^2 \int_{\underline{\varepsilon}}^{\bar{\varepsilon}} f(\cdot_i) f(\varepsilon) d\varepsilon \int_{\underline{\varepsilon}}^{\bar{\varepsilon}} f'(\cdot_j) f(\varepsilon) d\varepsilon - c''(s_j) \int_{\underline{\varepsilon}}^{\bar{\varepsilon}} f(\cdot_i) f(\varepsilon) d\varepsilon}{|\Delta|}, \tag{14}$$

which is negative regardless of the sign of f'. The effect of an increase in the royalty on the sampling performed by firm j, as captured by

$$\frac{\partial s_j}{\partial t} = \frac{(1-\gamma)^3 \bar{v}^2 \int_{\underline{\varepsilon}}^{\bar{\varepsilon}} f(\cdot_i) f(\varepsilon) d\varepsilon \int_{\underline{\varepsilon}}^{\bar{\varepsilon}} f'(\cdot_j) f(\varepsilon) d\varepsilon}{|\Delta|}, \tag{15}$$

depends, however, on the relation between s_i and s_j (that is, on the sign of f').

Proposition 1 *An increase in the tax rate on successful products in country i will increase country j's sampling intensity iff $f' > 0$.*

If the reaction function is negatively sloped (strategic substitutes), a higher royalty on firm i results in less domestic sampling and more sampling by firm j. This has the effect of significantly reducing the probability that firm i is successful in the competition. If the reaction function is however positively sloped (strategic complements), the higher royalty reduces the sampling intensities of both firms, thus having less of an impact on the probability that firm i is successful. For the same royalty rate, the government's expected revenues are then lower under strategic substitutability. Similar sensitivities can be found with respect to the per-unit charge p as

$$\frac{\partial s_i}{\partial p} = \frac{(1-\gamma)^2 \bar{v} \int_{\underline{\varepsilon}}^{\bar{\varepsilon}} f'(\cdot_j) f(\varepsilon) d\varepsilon - c''(s_j)}{|\Delta|}, \tag{16}$$

which is always negative, and

$$\frac{\partial s_j}{\partial p} = \frac{(1-\gamma)^2 \bar{v} \int_{\underline{\varepsilon}}^{\bar{\varepsilon}} f'(\cdot_j) f(\varepsilon) d\varepsilon}{|\Delta|}, \tag{17}$$

which, like the royalty, is positive when $f' > 0$ and is negative when $f' < 0$. In the section that follows, these sensitivities are used to determine the optimal government's choices of t and p.

4 Rent extraction and the choice of taxes

According to the 1992 UN Conference on Environment and Development in Rio de Janeiro, governments must protect their biological resources. The commonly cited difficulty in achieving such an objective is finding a source of funding. In addition to the recovery of biodiversity protection financing costs from bioprospecting, the government must take into account the impacts that its policies have on the likelihood the prospecting firm finds a successful product. In another way, the government must recognize the reactions of the sampling intensities of both firms from the second stage of the game in setting its own policies. The objective of the government is then to maximize the expected total revenues extracted from the firms, either through royalties or per-unit charges, subject to the constraint that firms act in accordance with the above detailed second-stage results. Consistently with Simpson et al., the social, ecological, moral or aesthetic values of biodiversity are ignored, as are the benefits of habitat protection (including ecotourism and recreation), so that the focus here is strictly on prospecting incentives.

Providing the samples to firm i has a cost $e(s_i)$ with $e' > 0$ and $e'' \geq 0$. This cost could relate to the actual provision of the samples or to the cost of preserving an area large enough to encompass enough species to meet the demand. The government thus maximizes its expected net revenues

$$R = t\bar{v}\int_{\underline{\varepsilon}}^{\bar{\varepsilon}} F((1-\gamma)(s_i - s_j) + \varepsilon_i) f(\varepsilon) d\varepsilon - e(s_i) + ps_i \tag{18}$$

with respect to both t and p, subject to the second-stage reaction functions of firms i and j. This yields the first-order conditions

$$\begin{aligned} \frac{\partial R}{\partial t} = -e'(s_i)\frac{\partial s_i}{\partial t} + p\frac{\partial s_i}{\partial t} + \bar{v}\int_{\underline{\varepsilon}}^{\bar{\varepsilon}} F((1-\gamma)(s_i - s_j) + \varepsilon_i) f(\varepsilon) d\varepsilon + \\ + t(1-\gamma)\bar{v}\int_{\underline{\varepsilon}}^{\bar{\varepsilon}} f((1-\gamma)(s_i - s_j) + \varepsilon_i) f(\varepsilon) d\varepsilon \left[\frac{\partial s_i}{\partial t} - \frac{\partial s_j}{\partial t}\right] = 0 \end{aligned} \tag{19}$$

and

$$\begin{aligned} \frac{\partial R}{\partial p} = t(1-\gamma)\bar{v}\int_{\underline{\varepsilon}}^{\bar{\varepsilon}} f((1-\gamma)(s_i - s_j) + \varepsilon_i) f(\varepsilon) d\varepsilon \left[\frac{\partial s_i}{\partial p} - \frac{\partial s_j}{\partial p}\right] \\ -e'(s_i)\frac{\partial s_i}{\partial p} + p\frac{\partial s_i}{\partial p} + s_i = 0 \end{aligned} \tag{20}$$

Upon substitution for p from the first-order condition of firm i's profit maximization, (5), into (19), it obtains that

$$t = \frac{\bar{v}\int_{\underline{\varepsilon}}^{\bar{\varepsilon}} F((1-\gamma)(s_i - s_j) + \varepsilon_i) f(\varepsilon) d\varepsilon + (1-\gamma)\bar{v}\int_{\underline{\varepsilon}}^{\bar{\varepsilon}} f((1-\gamma)(s_i - s_j) + \varepsilon_i) f(\varepsilon) d\varepsilon \frac{\partial s_i}{\partial t}}{(1-\gamma)\bar{v}\int_{\underline{\varepsilon}}^{\bar{\varepsilon}} f((1-\gamma)(s_i - s_j) + \varepsilon_i) f(\varepsilon) d\varepsilon \frac{\partial s_j}{\partial t}} -$$

$$- \frac{(c' + e')\frac{\partial s_i}{\partial t}}{(1-\gamma)\bar{v}\int_{\underline{\varepsilon}}^{\bar{\varepsilon}} f((1-\gamma)(s_i - s_j) + \varepsilon_i) f(\varepsilon) d\varepsilon \frac{\partial s_j}{\partial t}}. \tag{21}$$

Proposition 2 *A tax on successful products is more likely to be positive when the marginal cost of sampling is low, the degree of spillovers between firms (γ) is low, the value of a successful product ($\bar{v}$) is high, and the two R&D inputs are stronger strategic substitutes (that is, f' is higher).*

The tax on successful products lowers domestic firm's R&D efforts, thereby reducing the success probability of the domestic firm (increasing in extent with the value of f'). Low sampling costs and spillovers, or high product values, instead lead to high R&D and a high success probability

From (20), the relationship between p and t can be written as

$$p = \frac{-t(1-\gamma)\bar{v}\int_{\underline{\varepsilon}}^{\bar{\varepsilon}} f((1-\gamma)(s_i - s_j) + \varepsilon_i) f(\varepsilon) d\varepsilon \left[\frac{\partial s_i}{\partial p} - \frac{\partial s_j}{\partial p}\right] - s_i + e'\frac{\partial s_i}{\partial p}}{\frac{\partial s_i}{\partial p}}, \tag{22}$$

where t is given by (21). The first conclusion that can be drawn is that, if there is only to be one instrument (either a tax on successful products or a tax on sampling but not both), then the tax is certainly positive. This follows directly from the objective of revenue extraction of the government. Related to this, if one instrument is a subsidy, the other must be a tax. Again, this simply ensures that the government has a positive revenue flow. In general, however, a tax on successful products can be combined with either a tax or a subsidy on sampling, and a tax on sampling can be combined with either a tax or a subsidy on successful products.[16]

When the government applies a tax on sampling ($p > 0$), the conditions under which the optimal royalty is negative depend on the sign of f', or whether the R&D expenditures are strategic complements or substitutes. A subsidy (rather than a royalty) on successful products is then the desired choice of the government when

$$\bar{v}\int_{\underline{\varepsilon}}^{\bar{\varepsilon}} F((1-\gamma)(s_i - s_j) + \varepsilon_i) f(\varepsilon) d\varepsilon + (1-\gamma)\bar{v}\int_{\underline{\varepsilon}}^{\bar{\varepsilon}} f((1-\gamma)(s_i - s_j) + \varepsilon_i) f(\varepsilon) d\varepsilon \frac{\partial s_i}{\partial t} - (c' + e')\frac{\partial s_i}{\partial t} \tag{23}$$

is positive if $f' < 0$, or negative if $f' > 0$.

[16] In another way, there are three classes of possible outcomes with two non-zero instruments: $t > 0$ and $p > 0$, $t > 0$ and $p < 0$, and $p > 0$ and $t < 0$.

Proposition 3 *If the two sampling intensties are strategic substitutes, a tax on sampling* ($p > 0$) *would be more likely to be combined with a subsidy on successful products* ($t < 0$) *when the value of a successful product* (v) *is low, marginal sampling costs* (c') *are high, marginal protection costs* (e') *are high, and the degree of spillovers* (γ) *is high. However, the opposite is true if the two R&D expenditures are strategic complements.*

When the two expenditures are strategic substitutes, a lower product value or higher sampling costs, protection costs, or spillovers imply that the resulting decreases in R&D by the home firm lead to increased R&D by the foreign firm, thereby reducing the likelihood of success by the home firm. This contributes to lower expected revenues from the product as well as from the R&D tax. A product subsidy offsets these revenue decreases by encouraging sampling. With strategic complements, a higher product value or smaller sampling costs, protection costs, or spillovers lower both domestic sampling and foreign sampling, so that the likelihood of success does not change substanitally. As a result, the home government is more likely to choose to subsidize an uncertain success in return for higher R&D tax revenues from the higher sampling intensity.

In practice, royalty agreements have been employed to share profits between the firms and the source country, as intended by the Biodiversity Convention. Royalties are usually based on the expected value of the potential product, with royalty figures typically ranging from 1 to 7 percent. Costa Rica's Instituto Nacional de Biodiversidad (INBio) has signed agreements of this type with pharmaceutical firms Merck and Co., Eli Lilly and Co., and Bristol Myers Squibb in the search for sources of new pharmaceuticals from samples from the diverse species of Costa Rica's tropical forests. The 1991 INBio-Merck agreement has been renewed three times.

It has here been shown that, although a positive tax (royalty) on successful finds forces firms to sample fewer species than in the absence of regulation, this does not necessarily imply that the firm is less likely to win the R&D game presented here. The nature of the uncertainty may result in the two R&D expenditures being strategic complements, so that foreign competitors reduce their own expenditures when a domestic royalty is applied. In general, however, it is suboptimal for domestic governments to only tax successful products, as a combination of taxes (or subsidies) on successful products and sampling costs produce larger revenues than a single tax. It is not impossible for the appropriate tax on successful products to be negative.

What are the implications of this model for the viability of biodiversity prospecting as a source of revenues for conservation? The limited data from existing agreements makes it difficult to determine, particularly since existing contracts do not use all of the instruments prescribed here. Further, the type of uncertainty faced by research firms needs greater attention. Nonetheless, it is not unreasonable to expect that a greater share of revenues could be extracted if the taxes were chosen optimally. A number of studies, including Farnsworth and Soejarto (1985), Principe (1989), McAllister (1991), Aylward (1993), and Barbier and Aylward have attempted to place values on untested species in situ, with results ranging from US$44 to US$23.7 million. Barbier and Aylward estimate the expected royalty per sample to be US$233, which implies (given the assumed 2 percent royalty) that the expected net revenues per sample is $11650. Using their estimates (40 years, 2000 samples per year, 10 percent discount rate), the expected present value is almost $228 million, of which only $4.6 million is extracted by the government in royalties. However, there is no reason to believe that the chosen royalty is necessarily optimal. If the inputs of competing firms are strategic complements, significantly raising the royalty rate yields greater expected revenues to the government. Per unit charges, or a combination of per unit charges and royalties, may be also be a more attractive revenue-generating policy for governments.

5 Concluding Remarks

Many countries, particularly those at lesser stages of development, have become increasingly concerned with the ability of biodiversity contracts to finance conservation efforts. Initial agreement attempts have employed royalties, or a tax on net revenues, as a means to this end, but the effectiveness of this method has been shown to be highly dependent on the nature of the uncertainty in the R&D process and the spillovers that occur between firms. In general, it is appropriate to combine royalties and per unit charges (either of which, but not both, could in fact be subsidies instead of taxes) as such a policy mix has the additional benefit of shifting some of the risk associated with exploration onto those firms performing the search.[17]

Some recent studies have suggested that low values of the "marginal species" necessarily imply

[17] Two of the most successful bioprospecting contracts are between INBio and Merck & Co. in Costa Rica (signed in 1991) and between Astra Zeneca and the Natural Product Discovery Unit at Griffith University in Australia (signed in 1993). Both agreements involve a prospecting or research fee, which is however fixed rather than dependent on the numbers of samples used, plus a royalty on any significant discovery made from bioprospecting.

that biodiversity prospecting is a poor tool for conservation. Due to the extremely large numbers of species currently in existence, it is virtually uncontestable that *private* values from these species is negligible and below their marginal protection cost, despite potentially high social values not captured in market transactions. However, pharmaceutical patents often provide firms with substantial profits which exceed research and development, production, and distribution costs, so that rent extraction may indeed be a viable option for governments desiring to finance biodiversity conservation.

Although it remains unclear based on the existing literature as to whether, and to what extent, private-sector bioprospecting can be relied upon for the protection of biological diversity,[18] bioprospecting can certainly play a key role as an incentive-based or market-based revenue-generating device for governments that have the responsibility of protecting such resources. The overriding objective of the Convention on Biological Diversity is in fact sustainable development, which requires a balance between economic development through the utilization of genetic resources and conservation of biodiversity. To this end, the Convention recognizes national sovereignty over all genetic resources and provides that access to valuable biological resources be carried out on "mutually agreed terms" and subject to the "prior informed consent" of the country of origin. The fair and equitable sharing of the benefits arising out of the utilization of genetic resources is especially relevant to developing countries where most of the world's biodiversity can be found in that it contributes to fueling their economic and social development while reducing the financial burden of biological conservation they face. Recent advances in bioprospecting methods, which combine databases of natural history with ecological and evolutionary theory, to many industries (e.g., biological control, bioremediation, construction engineering, shipping, environmental monitoring, mining, industrial materials, manufacturing, and environmental restoration) are also likely to increase the economic benefits from bioprospecting in the future as more species are identified as useful.

The development of appropriate policy measures on, and contracts for, access and benefit-

[18] Estimated bioprospecting incentives range from $21/ha (Simpson et al.) to $9,177/ha (Rausser and Small, 2000). The discrepancy in estimates may be attributable to better search processes resulting from improved information. Recently, however, Costello and Ward (2006) show that the wedge between the two estimates ($21/ha and $9,177/ha) is likely to be the outcome of different assumptions about the values of key parameters of the economic and biological models used. Furthermore, based on more realistic and defensible assumptions about the values of these parameters, they conclude, consistently with Simpson et al., that bioprospecting cannot provide sufficient incentives for private-sector biodiversity conservation.

sharing requires however that consideration be given to uncertainty and information spillovers. In the context of a two-firm R&D model, royalties are in fact found to lower the research output of the taxed firm, thus reducing the expected government's revenues, when the research output of the competing firm is a strategic substitute as opposed to a strategic complement. Furthermore, a policy mix consisting of a tax on sampling and a subsidy on any successful product is found to be preferable, under certain parameter restrictions, when the two firms' R&D expenditures are strategic substitues.

References

[1] Aylward, B. A., *The Economic Value of Species Information and Its Role in Biodiversity Conservation: Case Studies of Costa Rica's National Biodiversity Institute and Pharmaceutical Prospecting - Report to the Swedish International Development Authority* (Environmental Economics Centre, London, 1993).

[2] Bagwell, K. and R. W. Staiger (1992), "The Sensitivity of Strategic and Corrective R&D Policy in Battles for Monopoly," *International Economic Review* 33, 795-816.

[3] Bagwell, K. and R. W. Staiger (1994), "The Sensitivity of Strategic and Corrective R&D Policy in Battles in Oligopolistic Industries," *Journal of International Economics* 36, 133-150.

[4] Barbier, E. B., and Bruce A. Aylward (1996), "Capturing the Pharmaceutical Value of Biodiversity in a Developing Country," *Environmental and Resource Economics* 8, 157-181.

[5] Barbier, E. B., J. C. Burgess, and C. Folke, *Paradise Lost? The Ecological Economics of Biodiversity* (Earthscan, London, 1994).

[6] Beattie, A.J., and P.R. Ehrlich (2004), *Wild Solutions: How Biodiversity is Money in the Bank* (Yale University Press, New Haven, 2nd edition).

[7] Brander, J. A. and B. Spencer (1985), "Export Subsidies and International Market Rivalry," *Journal of International Economics* 18, 83-100.

[8] Brown, G. M. and W. Henry, "The Economic Value of Elephants," in *Economics and Ecology: New Frontiers and Sustainable Development,* E. B. Barbier, editor (Chapman and Hall, London, 1993).

[9] Bulow, J., J. Geanakoplos, and P. Klemperer (1985), "Multimarket Oligopoly: Strategic Substitutes and Complements," *Journal of Political Economy* 93(3), 488-511.

[10] Carrizosa, S., S.B. Brush, B.D. Wright, and P.E. McGuire (2004), *Accessing Biodiversity and Sharing the Benefits: Lessons from Implementation of the Convention on Biological Diversity* (IUCN, Gland, Switzerland, and Cambridge, UK).

[11] Carrizosa, Santiago, Stephen B. Brush, Brian D. Wright, and Patrick E. McGuire (eds.) 2004. *Accessing Biodiversity and Sharing the Benefits: Lessons from Implementation of the Convention on Biological Diversity*. IUCN, Gland, Switzerland and Cambridge, UK. xiv+316 pp.

[12] Coe, D., and E. Helpman (1995), "International R&D spillovers," *European Economic Review*, 39, 859-887.

[13] Coley, P.D., M.V. Heller, R. Aizprua, B. Arauz, and N. Flores (2003), "Using Ecological Criteria to Design Plant Collection Strategies for Drug Discovery," *Frontiers in Ecology and Environment* 1, 421–428.

[14] Costello, C., and M. Ward (2006), "Search, Bioprospecting and Biodiversity Conservation," *Journal of Environmental Economics and Management*, 52, 615-626.

[15] Dixit, A. (1984), "International Trade Policy for Oligopolistic Industries," *Economic Journal*, S1-S16.

[16] Eaton, J., and G. M. Grossman (1986), "Optimal Trade and Industrial Policy under Oligopoly," *Quarterly Journal of Economics* 101, 383-406.

[17] Farnsworth, N. R., and D. D. Soejarto (1985), "Potential Consequences of Plant Extinction in the United States on the Current and Future Availability of Prescription Drugs," *Economic Botany* 39 (July-Sept), 231-240.

[18] Harvard Business School, "The INBio/Merck Agreement: Pioneers in Sustainable Development," *Paper No. NI-593-015* (Harvard Business School, Boston MA, 1992).

[19] Lazear, E., and S. Rosen (1981), "Rank-Order Tournaments as Optimal Labor Contracts," *Journal of Political Economy* 89, 841-864.

[20] McAllister, D. (1991), "Estimating the Pharmaceutical Value of Forests, Canadian and Tropical," *Canadian Biodiversity* 1(1), 16-25.

[21] Pearce, D. W., "An Economic Approach to Saving the Tropical Forests," *LEEC Discussion Paper 90-05* (LEEC, London, 1990).

[22] Pearce, D., and S. Puroshothamon, “Preserving Biological Diversity: The Economic Value of Pharmaceutical Plants,” *CSERGE Discussion Paper* 92-27 (CSERGE, London, 1992).

[23] Principe, P., *The Economic Value of Biodiversity Among Medicinal Plants* (OECD, Paris, 1989).

[24] Rausser, G., and A. Small (2000), ”Valuing Research Leads: Bioprospecting and the Conservation of Genetic Resources,” *Journal of Political Economy* 108(1), 173-206.

[25] Reid, W. V., S. A. Laird, R. Gámez, A. Sittenfeld, D. H. Janzen, M. A. Gollin, and C. Juma, “A New Lease on Life,” in *Biodiversity Prospecting: Using Genetic Resources for Sustainable Development,* W. V. Reid, editor (World Resources Institute, Washington, 1993).

[26] Rubin, S. M., and S. C. Fish (1994), “Biodiversity Prospecting: Using Innovative Contractual Provisions to Foster Ethnobotanical Knowledge, Technology and Conservation” *Colorado Journal of International Environmental Law and Policy* 5 (Winter), 23-58.

[27] Simpson, R. D., R. A. Sedjo, and J. W. Reid (1996), “Valuing Biodiversity for Use in Pharmaceutical Research,” *Journal of Political Economy* 104(1), 163-185.

[28] Sedjo, R. A. (1992), “Property Rights, Genetic Resources, and Biotechnological Change,” *Journal of Law and Economics* 35(April), 199-213.

[29] Spencer, B., and J. A. Brander (1983), “International R&D Rivalry and Industrial Strategy,” *Review of Economic Studies* 50, 707-722.

[30] Wilson, E. O., *The Diversity of Life* (Belknap, Cambridge MA, 1992).

[31] Zhou, H. (2003), “International R&D Competition and Industrial Policy,” mimeo.